Application of the ground anchor facility in Plaxis 3D Foundation

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Introduction

The ground anchor in Plaxis 3D Foundation consists of two different parts. The first part represents the free anchor length and the second part the grout body. The free length is modelled as a node-to-node anchor, which represents the connection between the grout body and e.g. a diaphragm wall, and the grout body consists of embedded beam elements, which are line elements with a special interface to model the grout-soil interaction. For the definition of the ground anchor eight input values are required (Fig. 1).

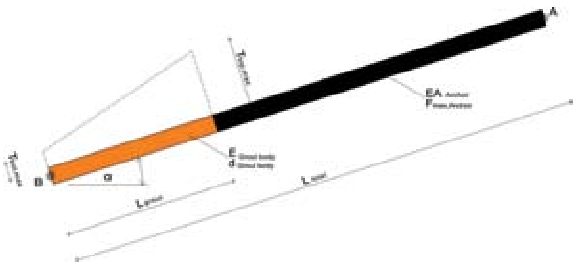

Figure 1: System layout and input values for a ground anchor

The soil-interaction is defined with the two separate values for skin resistance along the grout body. Thus it is possible to define a constant, linear or trapezoidal distribution of skin resistance. The maximum interaction force between the soil and the grout body is directly applied in the "interface" of the embedded beam.

It is pointed out that this represents the skin resistance at failure (i.e. when the pull out force is reached) and that the skin traction distribution below full mobilisation is influenced by the specified limiting distribution. In reality mobilisation will start at the top of the grout body and only close to the pull out force (failure) the skin traction at the bottom should be mobilised. In the embedded pile the mobilisation follows the predefined shape from the beginning (also at the bottom). However, tests have shown that this does not have a noticeable influence on the global behaviour of an anchored structure under working load conditions.

Another important point is, that for forces close to the theoretical pull out force numerical failure may occur due to plasticity in the soil adjacent to the grout body. Although this is of course possible in reality, in the model it may be artificial and caused by the fact that the grout body is a line element. To overcome this problem in ultimate limit state conditions it is necessary to work with an enlarged diameter of the grout body. This virtual diameter of the grout body is defined as follows:

$$D_{virtual} = f * D_{real}$$

In this equation f is the factor for the enlargement, and a value of f in the range of 2 – 4 is suggested. This does not affect the pull out force (this is an input due the input of the limiting skin resistance and the length of the grout body) and has minor effect on the behaviour under working load conditions. It follows, and the user must be aware of this, that when using this option in Plaxis 3D Foundation the maximum pull out force is an INPUT and cannot be OBTAINED from the analysis.

Deep excavation with prestressed ground anchors

In order to demonstrate the application of the ground anchors in Plaxis 3D Foundation, some results from a practical example, namely a deep excavation in Berlin sand, are presented. This example was chosen for testing the ground anchor facility under working load conditions because a 2D reference solution was available. The model dimensions and material sets for the soil layers have been taken from the 2D reference solution (Fig. 2).

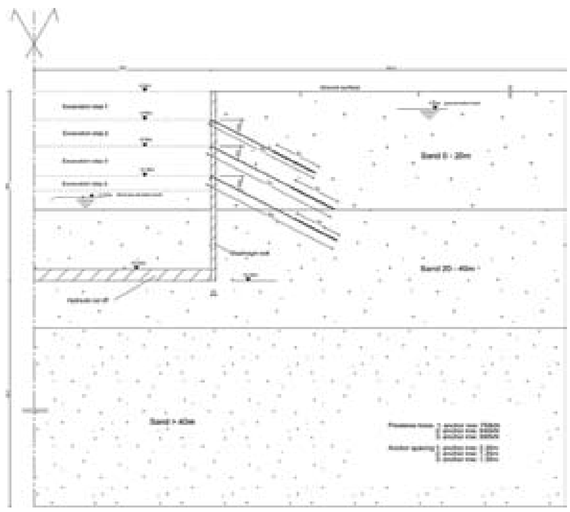

Figure 2: Geometry and subsoil conditions

The diaphragm wall has been modelled as a continuum element (Fig. 3), with linear elastic material behaviour and a stiffness Eref=3.0*E7 kN/m2. The hydraulic cut off does not act as a structural element, the properties are the same as for the soil (sand 20 – 40m).

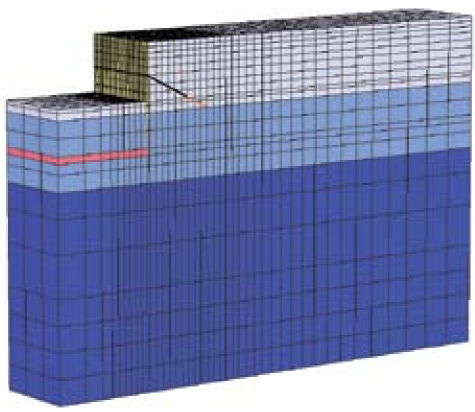

Figure 3: 3D view of the model (20944 elements)

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Continuation

To obtain the current porewater distribution inside the excavation the porewater pressure was defined after each groundwater lowering (with user defined pore pressure distribution). The ground anchors have different spacing and prestress forces in the different layers and therefore the anchor rods have different properties. The properties of the grout body are the same in all rows (Table 1).

Properties of the node-to-node anchor

	material type	EA	prestress force	spacing
anchor row 1	elastic	2.87*E5 kN	768kN	2.30m
anchor row 2	elastic	3.20*E5 kN	945kN	1.35m
anchor row 3	elastic	3.20*E5 kN	980kN	1.35m

Properties of the grout body

grout body	2*E7 kN/m2
diameter	0,125m

Table 1: Ground anchor properties

Aim of the test was to see if the embedded pile model (employed for the grout body) works well in working load conditions and therefore the skin resistance in the grout body has been defined about two times the expected axial load in the node-to-node anchor.
In the different calculations the material model, the shape of the limiting skin resistance and the enlargement of the grout body have been varied (Table 4).
In the following tables the soil properties for the MC and the HS-Model are summarized.

soil layer	γ_{unsat} [kN/m3]	γ_{sat} [kN/m3]	k [m/day]	$E_{50,ref}$ [kN/m2]	$E_{oed,ref}$ [kN/m2]	$E_{ur,ref}$ [kN/m2]	m [-]
sand 0 - 20m	17.0	20.0	-	45000	45000	180000	0.55
sand 20 - 40m	17.0	20.0	-	75000	75000	300000	0.55
sand > 40m	17.0	20.0	-	105000	105000	315000	0.55

soil layer	ν_{ur} [-]	p_{ref} [kN/m2]	$K_{0\,nc}$ [-]	c_{ref} [kN/m2]	ø [°]	ψ [°]	Rinter [-]
sand 0 - 20m	0.2	100	0.426	1.0	35.0	5.0	0.8
sand 20 - 40m	0.2	100	0.384	1.0	38.0	6.0	0.8
sand > 40m	0.2	100	0.384	1.0	38.0	6.0	-

Table 2. Soil parameters for the HS-model

soil layer	γ_{unsat} [kN/m3]	γ_{sat} [kN/m3]	E_{ref} [kN/m2]	ν [-]	c_{ref} [kN/m2]	ø [°]	ψ [°]
sand 0 - 20m	17.0	20.0	47000	0.3	1.0	35.0	5.0
sand 20 - 40m	17.0	20.0	244000	0.3	1.0	38.0	6.0
sand > 40m	17.0	20.0	373000	0.3	1.0	38.0	6.0

Table 3. Soil parameters for the MC-model

	material model	shape of the skin friction distribution	f-factor
calculation 1	HS	constant	1
calculation 2	HS	linear	1
calculation 3	HS	linear	2
calculation 4	HS	linear	4
calculation 5	HS	linear	4
calculation 6	MC	linear	1

Table 4. Variations in the different calculations

In calculation 5 the stiffness of the grout body has been changed according to the ratio of the real diameter (0.125m) to the fictitious enlarged diameter (0.125*f=0.5m).

Results

It follows from Figure 4 that neither the variation of the predefined limiting skin resistance of the grout body nor the f-factor for the enlargement of the grout diameter have a significant influence on the axial forces predicted under working load conditions. However the distribution of the mobilised skin traction along the grout body is not what one would expect in reality (Fig. 5). If the Mohr Coulomb model is employed the results are slightly different (Fig 6).

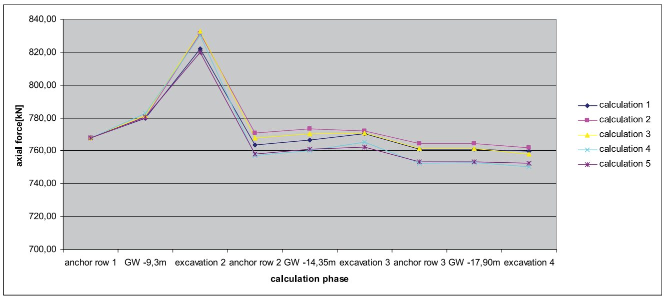


Figure 4: Axial forces in the first anchor row (calculation 1, 2, 3, 4, 5)

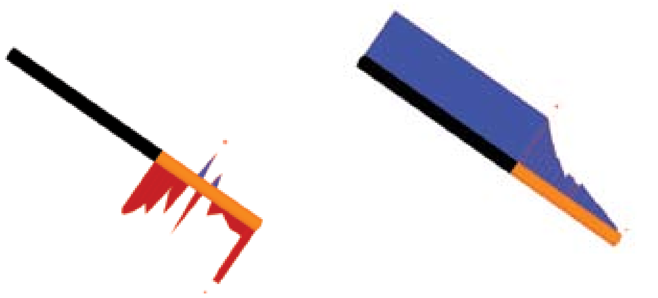


Figure 5: Mobilised skin friction and axial force – first anchor row (after excavation 4, calculation 1)

With respect to the horizontal displacements there is a trend that wall deflection with a linear predefined shape of the skin friction is slightly higher than the one with constant skin traction distribution. It is also notable that by increasing the f-factors for the virtual grout body diameter displacements in horizontal direction become smaller. The differences are in the order of 10%. With the MC-Model the highest deformations in horizontal direction are located around the grout body (Fig. 7), whereas with the HS-Model this is not the case. This effect also occurs with the assignment of a high f-factor.
The settlements behind the diaphragm wall are in the range of 11mm (almost the same for the different variations) with the HS model, but with the MC model there is a heave of more than 14mm, an effect which is well known.

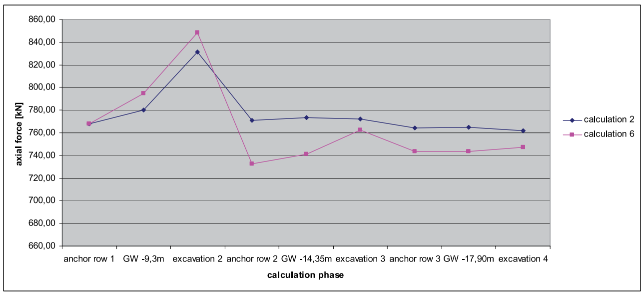


Figure 6: Axial forces in the first anchor row – calculation 2 vs calculation 6

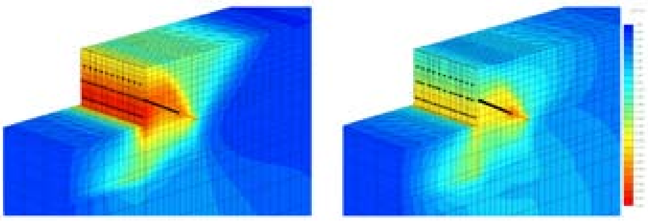
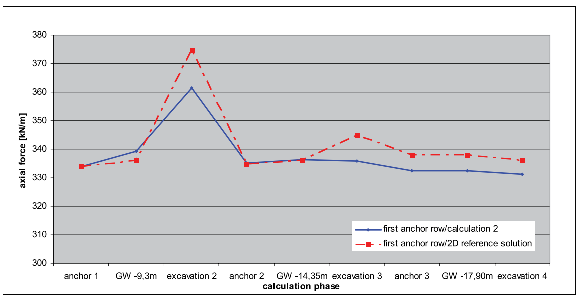


Figure 7: Horizontal displacements – left calculation 2 (HS-model), right calculation 6 (MC-model)

Comparison of 3d results with 2d reference solution

In Figure 8 axial forces in the first anchor row from calculation 2 (HS-model and f-factor=1) are compared with the axial forces from the 2D reference solution. In Plaxis V8 the grout body of a ground anchor is modelled with geogrid elements. These elements have an axial stiffness but no bending stiffness. The axial forces from Plaxis V8 are in the dimension [kN/m] and to compare these results with the 3D analysis it is necessary to divide the axial forces from Plaxis 3D Foundation by the anchor spacing of the different rows. One can see that the axial forces from the 3D calculations are in a very good agreement to the reference solution. The deviation of the forces in the node-to-node anchor between both calculations is less than 4%. Also the vertical displacements behind the diaphragm wall from the 3D calculation (Fig.9) are very similar to the ones obtained from the 2D solution (both maximum value and distribution).



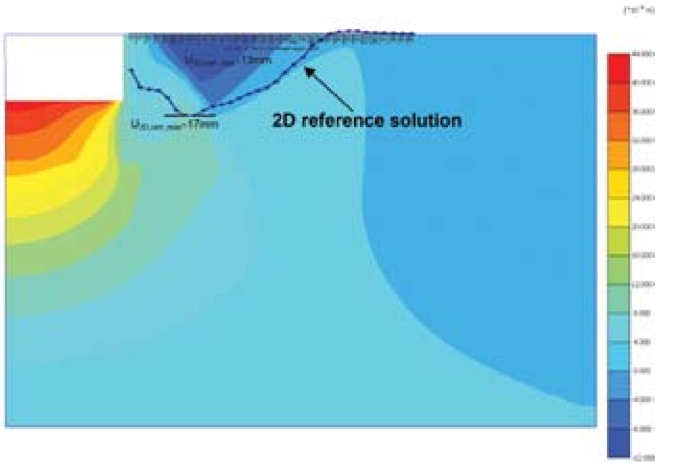


Figure 8: Axial forces calculation 2 vs. 2D reference solution

Figure 9: Vertical displacements behind the diaphragm wall – comparison reference solution with calculation 2

Conclusions

A deep excavation supported by a diaphragm wall and three rows of anchors has been analysed utilizing Plaxis 3D Foundation with the ground anchor option.

The results from the 3D calculation with the HS-Model compare well to the 2D reference solution (both with respect to anchor forces and displacements) and as a consequence from the parametric study it can be concluded that it is not necessary to artificially increase the diameter of the grout body for working load conditions.

Concerning the distribution of the skin friction along the grout body, it is obvious that the mobilisation is not realistic. The reason is, that also at working load conditions the distribution of the skin friction is strongly influenced by the distribution in the failure state, which is an input. Due to the fact that the limiting skin friction is an input the grout body length has no or minor influence on the result and therefore the length cannot be determined from the analysis.

Compared to the HS-Model the MC-Model predicts significantly larger deformations around the grout body. The virtual enlargement of the grout body diameter (f-factor) does not change the results significantly for working load conditions.

However for ultimate limit state calculations the f-factor becomes important, because in these calculations a premature failure (i.e. a failure below the theoretical pull out force) may occur when f=1.0. To overcome this problem it is essential to work with a virtual grout body enlargement.

It follows from this study that the ground anchor concept in Plaxis 3D Foundation is efficient for working load conditions, but for ultimate limit state analysis assumptions such as the f-factor, mesh coarseness and stiffness parameters of the soil (adjacent to the grout body) may have a significant influence on the result. It is emphasized again the maximum pull out force is an INPUT to the analysis and not a RESULT.